SEQUENCE STRATIGRAPHY OF THE GALVESTON SOUTH AREA OF THE GULF OF MEXICO

A Thesis

by

SANDRA E. BROOKS

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Approved as to style and content by:

Joel S. Watkins
(Chair of Committee)

Earl R. Hoskins
(Member)

Robert J. McCabe
(Member)

Joel S. Watkins
(Head of Department)

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ABSTRACT

Sequence Stratigraphy of the Galveston
South Area of the Gulf of Mexico
(August 1990)

Sandra E. Brooks, B.A., Vanderbilt University
B.S., Texas A&M University
Chair of Advisory Committee: Dr. Joel S. Watkins

Faults, salt, and proximity to the shelf edge determine the location of depocenters. Depocenters contain from 500-1100 ms ($\approx$1500-3300 ft) of sediment. Depositional rates range from 700 ms/Ma to 5000 ms/Ma. Time structure maps show an extensive down-to-the basin growth fault system and steep contours at the shelf edge. Four Pleistocene shelf edges, seen on seismic lines, prograde basinward through time. On the facies maps the paleo shelf edges coincide with progradational facies. Targets for oil and gas exploration are the deltaic depocenter and the stacked depocenters.

ACKNOWLEDGMENTS

I would like to thank the GMS^3 project for support. John Greene of Zapta Exploration provided a well log and paleo report for the shelf-break. Phillips Petroleum also provided well logs with corresponding paleo reports. I thank Jim Chodzko, Ahmad Ibrahim, and Su Yeong Yang for their thoughtful comments. I especially thank Joel Watkins for his guidance and encouragement. Finally, I would like to thank Jack Bryant for his support.

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CHAPTER I

INTRODUCTION

In the past fifteen years, improvements in shooting and processing seismic reflection data have given rise to seismic stratigraphy. Seismic stratigraphy as defined in American Association of Petroleum Geologists (AAPG) Memoir 26 (1977) is "the study of stratigraphy and depositional facies as interpreted from seismic data" (Mitchum et al, 1977). Seismic stratigraphy differs from structural seismic interpretation in that in seismic stratigraphy one locates unconformities on the basis of discordant seismic reflections whereas in a structural seismic interpretation the interpreter locates strong reflections. Sequence stratigraphy combines seismic stratigraphy, structural interpretation, and well data analysis. The combination of techniques helps the interpreter to infer depositional history.

An important part of the depositional history is the position of sea level. During lowstands in offshore Texas and Louisiana, growth faults developed, salt withdrawal formed depocenters, and the shelf progradation formed shelf edge delta systems. The depocenters and lowstand deltas often contain oil and gas reservoirs.

The present study is a sequence stratigraphic analysis of the Galveston South and northern East Breaks areas in the Gulf of Mexico. This study is part of the Texas A&M—University of Texas Gulf of Mexico Stratigraphic and Structures Synthesis Project supported by oil companies and oil company contractors.

This thesis follows the style and format of the *AAPG Bulletin*.

Objective

My objective is to gain an understanding of the structure and stratigraphy of the Galveston South and northern East Breaks areas of the Gulf. The Galveston South Area has fewer wells than neighboring areas. A better understanding of the convoluted structure of the area should indicate potential reservoirs. Growth faults and salt tectonism control the structure. Sediment loading on a prograding Pleistocene shelf initiated salt movement and growth faults. To gain an understanding of the structural evolution, one maps faults and salt diapirs and determines the timing of the salt movement. Mapping paleontological horizons leads to an understanding of stratigraphic and structural relationships. By placing the mapped units within a framework of sea level fluctuations one can begin to infer the depositional history. In this thesis I examine the depositional environment and show the relationship of depocenters to salt, faults, and shelf edges.

Location and Environment

The study region, located roughly 80-160 km from the Texas coastline, includes the Galveston South and northern East Breaks areas (Figure 1). The region is located between 27°48′ to 28°12′N latitude and 94°31′ to 95°16′W longitude. The area of the region is 1115 km^2. Water depths range from approximately 61 m to the shelf edge at 183 m. Depositionally, the region extends from a middle shelf environment to the shelf edge.

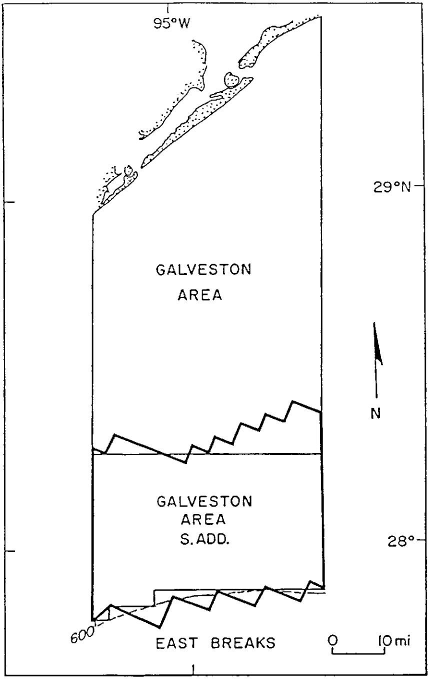


Figure 1. Index map of study area.

History of the Gulf of Mexico

The Gulf of Mexico is a small ocean basin which formed during Jurassic time (Martin and Bouma, 1978). Middle Jurassic rifting (approximately 180-140 Ma) created an uneven crust composed of many subbasins. Mantle upwelling created a medial uplift. During rifting, volcanics and continental sediments such as the Eagle Mills red beds filled the half graben rift basins (Buffler, 1980). During late rifting each side of the uplift began to subside and admit seawater, which evaporated leaving evaporite deposits. The most notable of the evaporites are the Jurassic Louann salt deposits which source diapirs several kilometers in height. The southern part of the deep Gulf equivalent of the Louann is the Challenger. Although physically discontinuous, the Louann and Challenger are contemporaneous (Watkins et al, 1978). They were probably once continuous, but have drifted apart. The Norphlet formation, an aeolian sand, overlies the Louann. Overlying the Norphlet is the Smackover, a Jurassic limestone, which marks the onset of marine deposition in the Gulf. Sea level was high and temperatures warm during the Cretaceous period; the southern edge of the North American continent was flat with little erosion. These conditions favored carbonate deposition which today rims the Gulf.

The Laramide Orogeny produced the Rocky Mountains in the early Tertiary. Rivers eroded the mountains and carried clastic sediment into the Gulf of Mexico. These Tertiary clastics overlie Cretaceous carbonates. By the Neogene, the Mississippi River had become the primary transporter of clastic sediments. Mississippi River sediment, which rapidly prograded basinward, repeatedly formed deltas and fans. Lowstand Pleistocene deltas and fans include many clean reservoir sands that are sought as exploration targets.

CHAPTER II

BACKGROUND

The Texas-Louisiana shelf is a terrigenous clastic province whose relatively smooth surface is interrupted by salt domes piercing the surface (Stuart and Caughey, 1977; Martin and Bouma. 1978). The surface shows local relief imposed by sea level fluctuations during the Pleistocene (Martin and Bouma, 1978). River channels cut pathways through the shelf during Pleistocene lowstands (Stuart and Caughey, 1977; Martin and Bouma, 1978). During lowstands, sediment loading at the shelf edge produced growth faults. The regional shelf edge is normally about 120 m subsea (Martin and Bouma, 1978), but in the Galveston South Area, the shelf edge is at a water depth of 183 m.

Depositional Environment

During the Tertiary, sedimentation was sufficiently rapid in the northwest Gulf to cause the shelf edge to prograde 400 km (Woodbury, 1973). The shelf edge, which is the break in slope between the continental shelf and continental slope, prograded basinward during two distinct Pleistocene lowstands (cool periods) (Woodbury, 1973; Sidner et al, 1978). Poag and Valentine (1976) similarly note two distinct climatic, tectonic, and depositional regimes during the Pleistocene. Core analysis indicates the water depth of deposition (Sidner et al, 1978). Although most of the shallow water deposits formed deltas, some formed low energy gravity flows (Sidner et al, 1978). Comparison of paleoclimates and seismic facies showed that the shelf prograded during cool periods (Sidner et al, 1978). They also found less fragmentation of planktonic foraminiferal tests during a cool period. This finding suggests an increase in upper slope sedimentation rates. Increased sedimentation rates typically accompany a relative fall in sea level.

Stuart and Caughey (1977) give a detailed explanation of facies classification on the basis of seismic character in the northwest Gulf of Mexico. They verified their seismic interpretation with borehole data. They note three distinct units: chaotic zones, weak or reflectorless zones, and zones with strong parallel reflectors (Stuart and Caughey, 1977). Chaotic zones probably result from secondary modifying mechanisms such as slumps and slides (Stuart and Caughey, 1977). These slumps and slides generally occur on the slope, while weak and strong reflector intervals appear on the shelf. Inclined stratification is typical of a prodelta environment and suggests that the shelf edge is near. A chief indicator of the shelf edge is the faunal boundary (Woodbury, 1973). Benthic neritic organisms dwell on the shelf while planktonic organisms float in the slope environment. This boundary is evident in well cores. On the seismic section, however, the shelf edge appears as an oblique progradational facies (Sidner et al, 1978). Prodelta deposits as well as fluvial and transgressive deposits display as weak reflectors. Deltas, on the other hand, have a strong, discontinuous reflection pattern with high angle clinoforms (Stuart and Caughey, 1977; Suter and Berryhill, 1985).

Deltas

Suter and Berryhill (1985) recognize in the northwest Gulf of Mexico five late Quaternary fluvial-deltaic systems. All of these are lowstand, shelf margin deltas. A shelf margin delta differs from shelf delta: A *shelf delta* is a "widespread thin sequence marked by low-angle clinoforms and numerous buried channels." A *shelf margin delta* is a "localized wedge-shaped sequence of increased thickness and steepened, well developed clinoforms" (Suter and Berryhill, 1985). The areal extent along strike of a shelf margin delta can exceed 5000 km^2 and 180 km perpendicular to strike (Suter and Berryhill, 1985). Shelf margin deltas have arcuate to lunate geometries parallel to depositional strike (Stuart and Caughey, 1977; Suter and Berryhill, 1985). In the northwest Gulf of Mexico, river-mouth switching and fluctuations in sea level have produced multilobate shelf margin deltas (Lehner, 1969; Suter and Berryhill, 1985).

Depocenters

Deltas are often areas of maximum sediment accumulation or depocenters. During Plio-Pleistocene time, sediments accumulated rapidly and the main Gulf of Mexico depocenter shifted from the mouth of the Mississippi River to a point 160 km south of the present shoreline near the Texas-Louisiana border—a westward shift of 320 km (Woodbury et al, 1973). At the same time, the shelf edge prograded gulfward 80 km. Depocenters occur where the shelf edge has prograded most rapidly. Woodbury et al (1973) believe that the present shelf edge dates from Pleistocene time. The Pleistocene depocenter, centered near the shelf edge offshore Texas and Louisiana, contains more than 4000 m of sediment (Poag and Valentine, 1976). It is located in the southern structural province of Woodbury et al (1973).

Salt

Woodbury et al (1973) divide the Texas-Louisiana offshore area on the basis of salt distribution into northern, central, and southern structural provinces. The northern province consists of small isolated diapirs. The central province consists of large isolated diapirs connected by a network of growth faults. The southern province consists of semicontinuous diapiric uplifts. The present study area straddles both the central and southern structural provinces.

Lateral salt movement results from sediment loading at the shelf edge (Lehner, 1969; Woodbury et al, 1973). Sandy foreset beds of Plio-Pleistocene age prograded across a mobile substrate of Miocene age mud and Jurassic age salt (Lehner, 1969; Woodbury et al, 1973). As a result, shale ridges developed; salt moved laterally; and masses of sediment slid down the upper slope filling the intra-slope basins with slump deposits and turbidites (Lehner, 1969; Woodbury et al, 1973). The structural signature is contorted and complex.

Biostratigraphy

The present study uses extinction data for four foraminifera: *Trimosina denticulata (Trim A)*, *Hyalinea balthica (Hyal b)*, *Angulogerina B (Ang B)*, and *Globoquadrina altispira (Glob alt)* (Basal Nebraskan). I first review the extinction data of the four species. *Trim A*, a benthic foraminifer which lived in the middle shelf to lower slope, became extinct during the third transgression (.65 Ma) (Poag and Valentine, 1976) (Figure 2). Just prior to the extinction of *Trim A* the basin approached isostatic equilibrium. There was an increase in the accumulation rate of sediments while there was a decrease in the subsidence rate of the basin. *Hyal b*, another benthic foraminifer which lived in a deep outer shelf-lower slope environment, became extinct at the end of a Pleistocene transgression (1.1 Ma) (Figure 2).

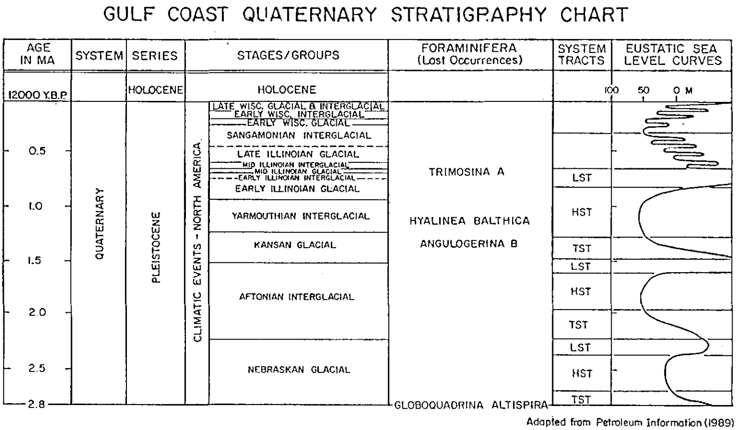


Figure 2. Gulf coast quaternary stratigraphy chart. This chart shows temporal relationships of glacial stages to formaminiferal extinction data.

Prior to the extinction of *Hyal b*, both accumulation rates and subsidence rates were great. The *Ang B* foraminifer is the index fauna for the middle Pleistocene, 1.3 Ma. *Ang B* is the condensed section at the top of a transgressive systems tract (Figure 2). This benthic foraminifer tolerated a warm outer shelf to lower slope environment (Dunlap, personal communication; Shaffer, 1987). Investigators disagree on the age of the Pliocene-Pleistocene boundary. The present study places the boundary at 2.8 Ma. This boundary coincides with the extinction of the planktonic species *Glob alt* and the base of the Nebraskan Glacial cycle (Beard et al, 1982). Fission-track dates and nanofossil dates support the early boundary of 2.8 Ma (Beard et al, 1982). *Glob alt* lived in the outer shelf to abyssal plain (Dunlap, personal communication).

Faults

Faults are common in the Gulf. Faulting accompanies formation of salt domes due to local stresses imposed by the rising salt (Cloos, 1968; Shelton, 1968). Faulting occurs at the shelf edge where the underlying sediments give way under the load of the prograding sediments (Galloway, 1986).

Offshore Texas regional fault trends consist of normal, down-to-the-basin growth faults (Garrison and Martin, 1973). The dip of the fault plane ranges from 70° near the surface to 35° at depth (Garrison and Martin, 1973). Growth faults or syndepositional faults are identified by an increase in thickness on the downthrown block. These beds of increased thickness are usually referred to as expanded sections. Increased thickness results in greater displacement with depth on the downthrown side of faults (Garrison and Martin, 1973). Growth faults allow circulation of ground water and provide channels for the migration of hydrocarbons (Galloway, 1986). Fault systems may also form seals for fluid and in this case may provide traps for hydrocarbons (Galloway, 1986).

CHAPTER III

METHODS

Teledyne Exploration Company has provided over 1610 km of 1971-1972 unmigrated twenty-four fold seismic reflection profiles with a grid spacing of 6.4×6.4 km. Air guns supplied the energy for the acquisition of the seismic data.

Mapping Faults and Salt

Faults and salt dominate the Galveston South Area. Offset in the reflections as well as curved diffractions indicate faults. I transferred both the position of the fault and the horizontal displacement, or heave, from the seismic section to the fault map. A strong doublet enclosing or capping a zone of chaotic reflections signifies salt (Figure 3). The salt distribution map, with a datum of four seconds, divides salt into shallow, intermediate and deep penetrating intervals. Salt and faults are the two major structural interruptions in the paleo-horizons.

Mapping Pleistocene Paleo-Horizons

I mapped four Pleistocene paleontological horizons by correlating with High Island and Brazos South horizons, by correlating with paleontologic reports and velocity surveys where available, and by locating terminations where evident. The four horizons are: *Trim A*, *Hyal b*, *B Ang B*, and *Glob alt* (Basal Nebraskan). I correlated the paleo-horizons from one line to another by the traditional method of tying loops. I then transferred each horizon to a time structure map. Each structure map includes the salt structures and faults which penetrate the horizon. The next group of maps is the set of isochron, or time interval, maps. These maps display the thickness in time between two horizons.

Mapping Seismic Facies

The seismic facies map shows the distribution of seismic patterns within a given isochron interval. Within a given interval the seismic character changes. Facies analysis is used to interpret depositional environments. The ten seismic facies patterns which appear in the study area are illustrated in Figure 4 (Sangree and Widmier, 1977). The two progradational facies, progradation and complex sigmoid-oblique progradation, are confined to the shelf edge and upper slope. Progradation implies the basinward development of depositional surfaces. Complex sigmoid-oblique progradation refers to alternating sigmoid and oblique progradational patterns within a seismic facies unit (Mitchum et al, 1977). Within a high energy regime, upbuilding and depositional bypass alternate in the topset beds (Mitchum et al. 1977). Hummocky and chaotic patterns are seen in shelf as well as shelf edge-upper slope environments. Hummocky reflections are generally associated with shallow water deposition in a prodelta or inter-deltaic position (Mitchum et al, 1977).

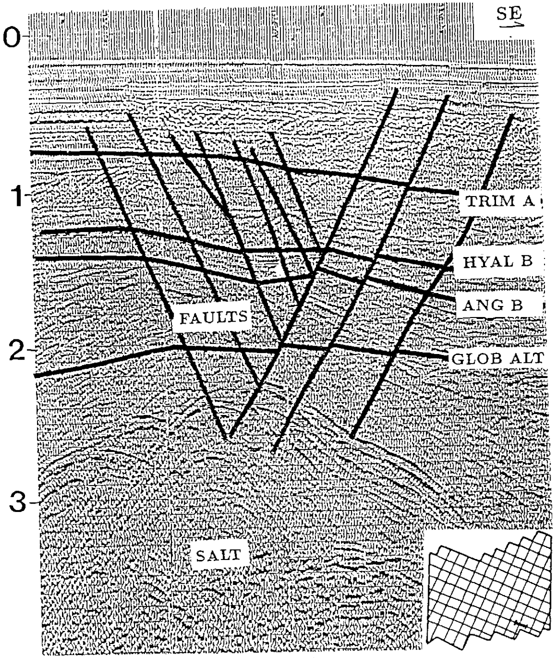
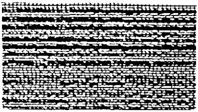
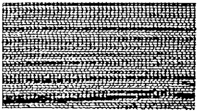


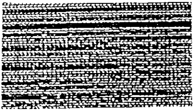
Figure 3. Seismic line showing the effect of salt movement. Thinning during *Hyal b-Ang B* indicates salt movement during that time.



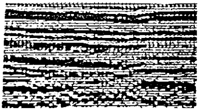
High-Amplitude Continuous (HC)



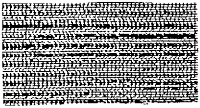
Low-Amplitude Continuous (LC)



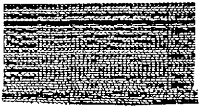
Variable-Amplitude Continuous (VC)



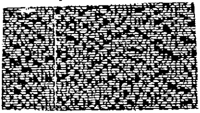
High-Amplitude Discontinuous (HD)



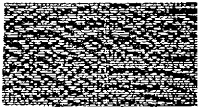
Low-Amplitude Discontinuous (LD)



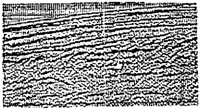
Variable-Amplitude Discontinuous (VD)



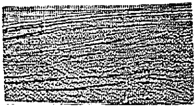
Chaotic (CH)



Hummocky (HM)



Progradation (P)



Complex Sigmoid-Oblique Progradation (CSOP)

Figure 4. Example facies patterns. These facies patterns are examples of the facies prevalent within the study area.

On the shelf, chaotic zones surround salt domes. On the upper slope, chaotic zones result from slumping and salt movement. Variable amplitude continuous reflections indicate interbedded high and low energy deposits. This reflection pattern occurs mainly in a shelf environment. Variable amplitude discontinuous reflections are most common. Their common occurrence may be the result of data processing and faulting. On the shelf this pattern is associated with non-marine clastics deposited by rivers (Sangree and Widmier, 1977). High amplitude discontinuous reflections are high amplitude continuous reflections which have been interrupted by faults. High amplitude continuous reflections appear on the shelf and are typically interpreted as either shallow marine clastics deposited by wave transport processes or fluvial clastics interbedded with marsh deposits (Sangree and Widmier, 1977). Low amplitude continuous and discontinuous patterns appear on the shelf. These patterns indicate uniform energy deposits which may be interpreted either as marine clastics deposited by low energy turbidites and wave transport or as fluvial and nearshore clastics deposited by fluvial and wave transport processes (Sangree and Widmier, 1977).

CHAPTER IV

RESULTS

Fault Map

The faults in the study area form systems near the shelf edge (Figure 5). To the southeast the faults cut the present shelf edge at a 30° angle but lie parallel to the shelf edge in the southwest.

Salt Distribution Map

Figure 6 shows the locations and depths of the salt bodies within the area. Correlation between paleo markers and glacial or interglacial stages is found in Figure 2. For example, salt which moved during the *Hyal b-Ang B* interval moved during the Kansan glacial stage. Time of salt movement is based on times of salt withdrawal evident in basins adjoining the salt bodies. The salt massif at the Galveston South-East Breaks boundary began to form during *Ang B-Glob alt* time as evidenced by the reflectors diverging towards the salt. Most salt movement occurred during *Hyal b-Ang B* time (Figure 3). Two large salt stocks slightly east of 95°W nearly merge. The northernmost stock has a shallow ramp on its eastern side. The western part of the stock is deeper, containing intermediate level salt (two to four seconds deep in two-way travel time). This stock appears to have moved throughout the Pleistocene. Shallow salt appearing in the northern part of the area pierces the seafloor indicating that it is moving today. Salt withdrawal directions (arrows) are random.

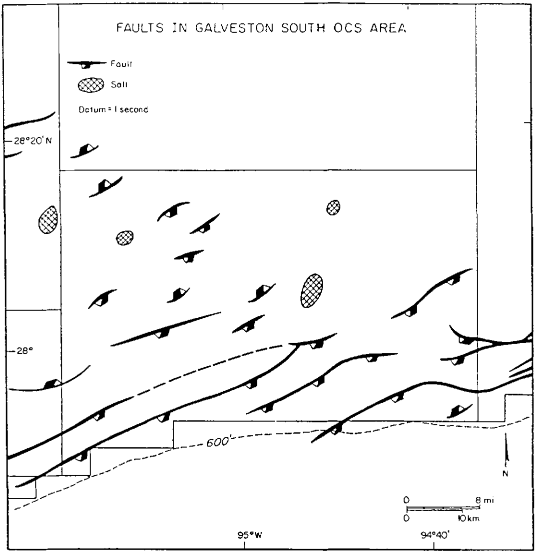


Figure 5. Fault map. Fault systems develop near the shelf edge. Salt bodies at this datum appear north of 28° N latitude.

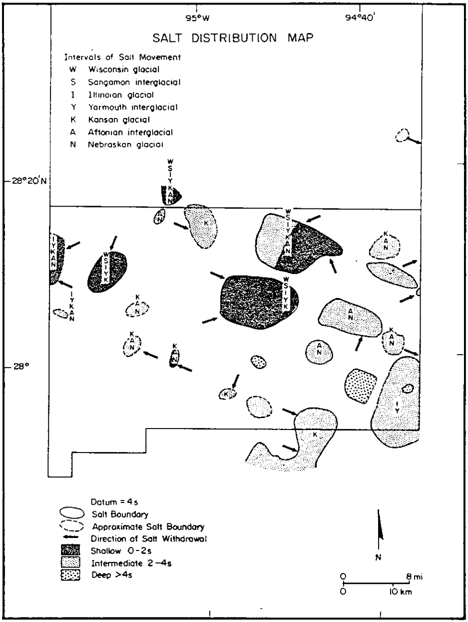


Figure 6. Salt distribution map.

Salt-Depocenter Map

Figure 7 shows the relationship of depocenters to salt. All depocenters are salt withdrawal basins and with one exception are located near the Galveston South-East Breaks boundary. The exception is G97, an 1100 milliseconds (ms) thick depocenter. This depocenter accumulated thick sediments during *Ang B-Glob alt* time. Salt associated with this basin lies in High Island to the southeast and in the Galveston Area to the northwest. Although the salt body to the northwest lies outside the data coverage area, evidence that it exists comes from a salt withdrawal wedge and upturned reflections going into the salt (Figure 8).

The other six depocenters lie close to the Galveston South-East Breaks boundary. During *Ang B-Glob alt* time, two 1100 ms thick depocenters formed, G97 and G224. Depocenter G97, already discussed, formed in the north while the second formed in the southeastern part of Galveston South. Salt surrounds this depocenter. Deep salt northwest of the depocenter caused slumping within the depocenter as the salt withdrew from beneath the depocenter towards the neighboring salt (Figure 9).

The *Hyal b-Ang B* depocenter, E111, lies within the East Breaks salt province. Sediments 500 ms thick accumulated in a rollover structure of a growth fault which roots in salt. As salt withdrew, the overlying sediments dropped down in blocks divided by faults to fill the void (Figure 10).

The *Trim A-Hyal b* interval has two 600 ms thick depocenters, G241 and G245. Both depocenters are located adjacent to salt structures. The two salt stocks north of the western depocenter as well as the large salt body in East Breaks affect the depocenter. The eastern depocenter for this interval lies between the large East Breaks salt massif and a deep salt structure north of the depocenter.

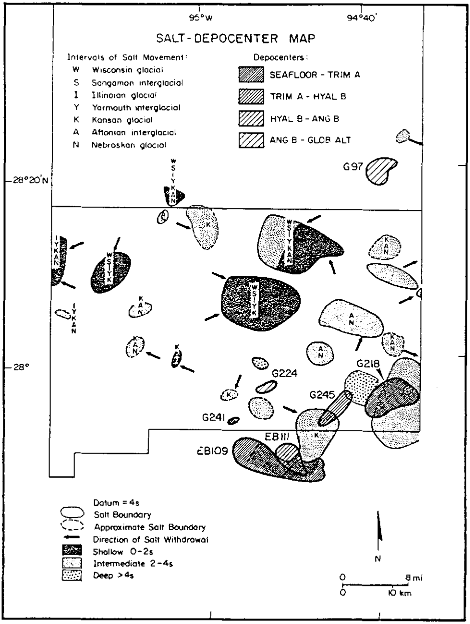


Figure 7. Salt-depocenter map. The superposition of the depocenters on the salt map shows the influence of salt and salt withdrawal on depocenters.

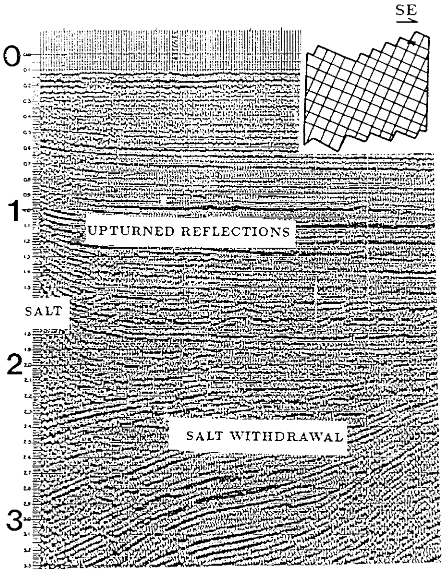


Figure 8. Seismic line indicating salt. Upturned reflections and salt withdrawal patterns point to salt outside data coverage.

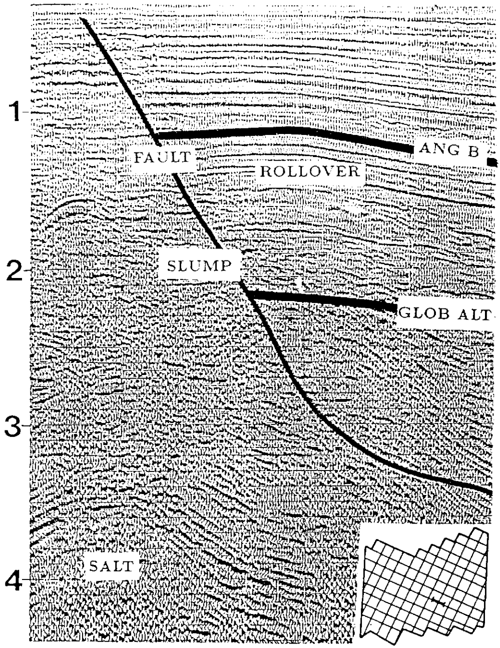


Figure 9. Seismic line of depocenter *Ang B-Glob alt*. In the *Ang B-Glob alt* depocenter, downbending reflections indicate slumping. Curved reflections at the top indicate rollover into a fault.

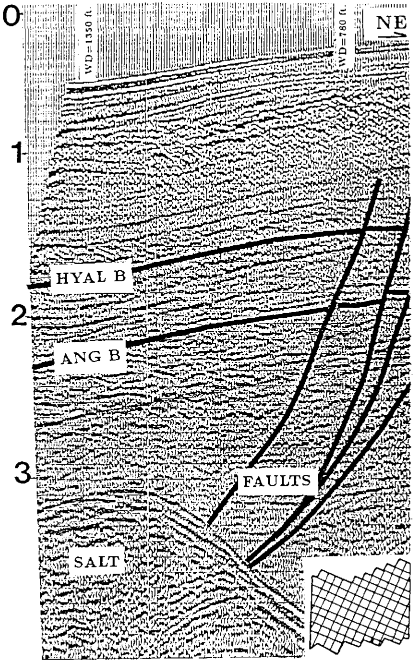


Figure 10. Seismic line of depocenter *Hyal b-Ang B*. The *Hyal b-Ang B* depocenter formed near the shelf edge in a salt and fault controlled regime.

The eastern Seafloor-*Trim A* depocenter, G218, is 1000 ms thick and lies on the eastern edge of the deep salt body overlying a large intermediate salt mass at the eastern Galveston South boundary. The second Seafloor-*Trim A* depocenter, E109, is 900 ms thick, covers a large area in East Breaks, and overlaps the *Hyal b-Ang B* depocenter. This depocenter is part of the East Breaks salt withdrawal basin. Salt is withdrawing from underneath the depocenter into the prominent East Breaks salt massif.

Time Structure Maps

The time structure maps reveal simple structures in the north and complex structures in the south. Reflectors generally dip basinward to the southeast. Shelf edge faults and salt movement disturb the general trend creating local mounds and depressions. Dip increases from north to south. To the north isolated basinward facing faults as well as isolated landward facing faults appear, while to the south complex interconnected faults control the horizons.

The oldest and deepest mapped horizon is *Glob alt* or Basal Nebraskan (Figure 11). The base of the hummocky to chaotic zone marks the *Glob alt* horizon (U.S. Department of Interior, 1987). Time-depths vary from 800 ms in the northwest to 2700 ms in the southeast (Figure 11). A 1700 ms depression lies west of the southern stock. Numerous faults interrupt the *Glob alt* horizon including several sets of parallel landward dipping faults near large salt domes. The anastomosing faults in the northeastern part of the region reflect the presence of salt below the mapped horizon in the neighboring High Island Area. The 1200 ms structural high west of 95°W 28°N is due to salt pushing the sediments upward.

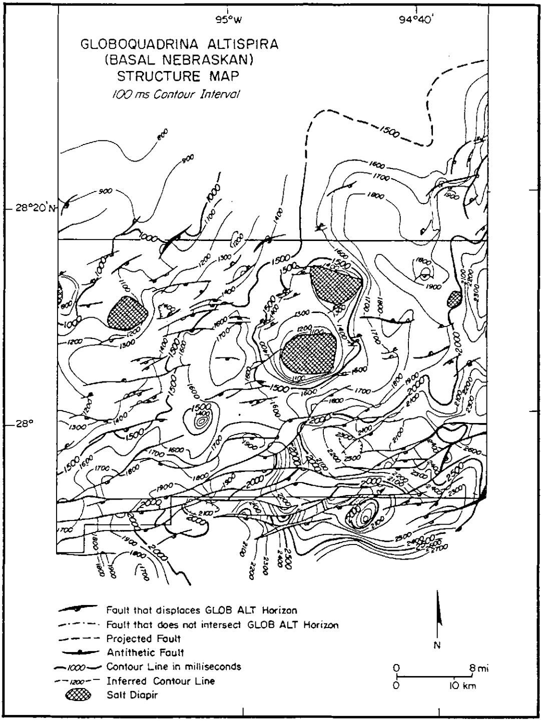


Figure 11. *Glob alt* structure map. The steepening contours in the south-east corner indicate the edge of the East Breaks salt withdrawal basin.

To the south the faults interweave, cutting through alternating structural highs and lows which occur along the Galveston South-East Breaks boundary. At this boundary west of 95°W, three mounded features and a high due to salt alternate with lows. At the southern limit of the mapped area the contours range from 1700 ms in the west to 2700 ms in the east.

Ang B time-depths range from 600-2200 ms and dip southeast. Fault systems trend northeast-southwest (Figure 12). By *Ang B* time the shelf edge had prograded basinward so that the faults make a 30° angle with the present shelf edge. Upward salt movement in the southeast corner of the map produces two 1500 ms highs. Adjacent to the structural highs lies the deepest contour of the horizon, 2200 ms, which marks the edge of the East Breaks salt withdrawal basin. A 2000-2200 ms thick depression occurs downthrown from a fault in the southeastern part of the area. The fault roots in the underlying neighboring salt. This salt body causes the 1800 ms thick high to the south.

The next horizon is *Hyal b*. This boundary is in a highstand (Figure 2). *Hyal b* structure is simpler than *Ang B* structure. In the north, the horizon dips gently southeast and steepens southward (Figure 13). Time-depths range from 500 ms across the north to 1700 ms in the southeast. Structural highs and lows alternate at the Galveston South-East Breaks boundary. The deepest contour of the horizon is between two salt cored structural highs in East Breaks.

Trim A, the shallowest mapped horizon, gently dips southeast from depths of 400 ms across the north to 1500 ms in the southeast (Figure 14). Few faults interrupt the horizon as faults seen do not always pierce the horizon. The alternating highs and lows evident in other horizons at the Galveston South-East Breaks boundary are more undulatory and less abrupt than in *Trim A* time. Salt underlies the enclosed 700 and 1000 ms highs in the eastern East Breaks Area.

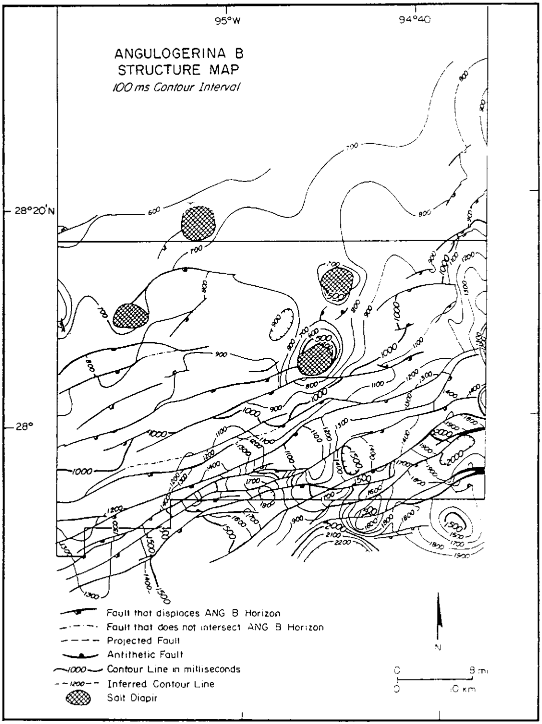


Figure 12. *Ang B* **structure map. Salt domes pierce the horizon in the northern part of the area. The 1500 ms high in the southeast corner is due to underlying salt.**

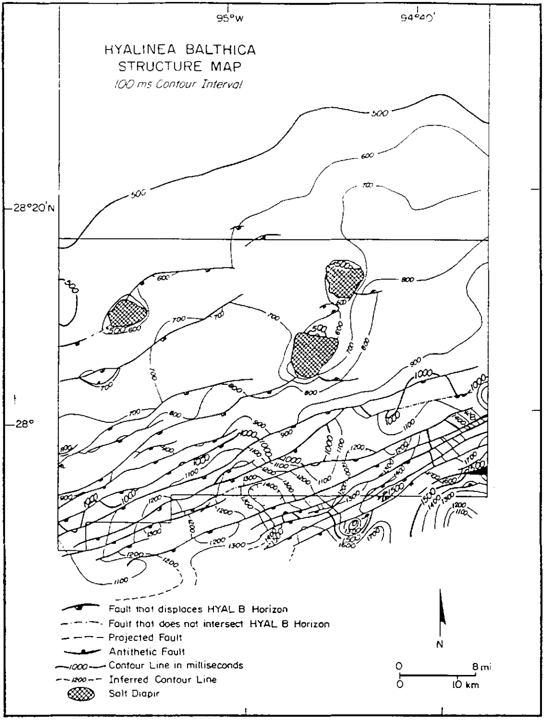


Figure 13. *Hyal b* **structure map.**

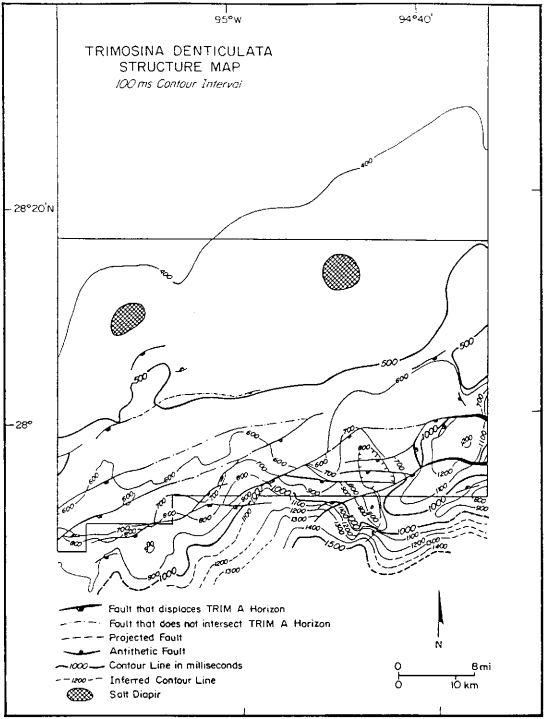


Figure 14. *Trim A* **structure map.**

Isochron (Time-thicknesses) Maps

Time-thickness ranges from 200 to 1100 ms in the *Ang B-Glob alt* interval (Figure 15). There are two 1100 ms thick depocenters: one in the northeast part of the area and the other in the south central part of Galveston South. Thickness distribution suggests that sediment traveled into the depocenters from the north down through lows created by salt withdrawal. Sediment pathway arrows follow the pattern suggested by seismic data, structure, and isochron maps. Figure 7 shows that the southern *Ang B-Glob alt* depocenter lies south of a deep salt body and north of an intermediate salt body. The fault associated with the depocenter contains slump deposits (high energy) and a rollover structure (Figure 9). The thinnest interval, 200 ms, runs into the Brazos Area. Two other thin intervals, both 300 ms thick, occur near the Galveston South-East Breaks boundary.

Hyal b-Ang B isochrons vary from 100-500 ms (Figure 16). Only one depocenter appears. This depocenter, 500 ms thick, lies in the East Breaks Area downthrown from a fault. Thickness distribution and the shape of the contours suggest two possible sediment pathways through the lows adjacent to salt bodies. The depocenter is lodged in between two lobes of a large salt mass. The thinnest interval is a 100 ms thick interval located between 95° W and the sediment transport arrow. This thin interval is located directly above the *Ang B-Glob alt* depocenter. During *Ang B-Glob alt* time a mounded feature appeared here which accounts for the thickening during that time (Figure 15). Only three major faults disrupt this interval in contrast to the complex structure of the previous interval.

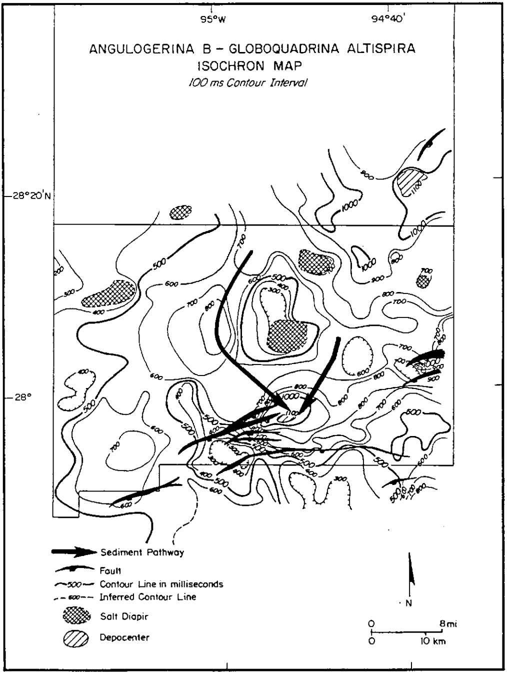


Figure 15. *Ang B-Glob alt* isochron map. There are two 1100 ms depocenters, one in the northeast and the other in the south.

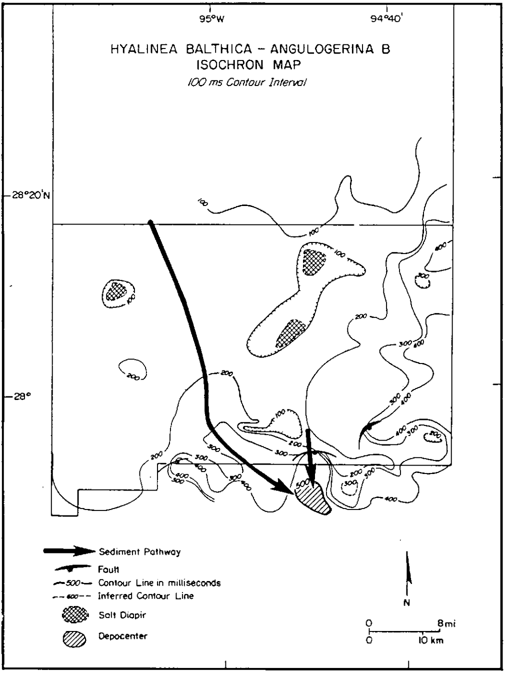


Figure 16. *Hyal b-Ang B* isochron map. Two sediment pathways converge at the upper slope depocenter.

The *Trim A-Hyal b* interval thickens from 100 ms around a diapir in the northwest to a maximum of 600 ms near the Galveston South-East Breaks boundary (Figure 17). After attaining its maximum thickness, the interval thins to 200 ms across the southern limit of data. This interval displays two 600 ms thick depocenters. The large salt domes east of 95°W separate the two sediment pathways. Three 200 ms thick salt cored enclosures lie at the southern extent of the area.

In the shallowest interval, Seafloor-*Trim A*, thicknesses vary from 200-1000 ms (Figure 18). The 200-ms thins surround the salt stocks in the central part of the area. The southern depocenter, 900 ms thick, overlies the *Hyal b-Ang B* depocenter. Seismic lines and thickness distribution on the isochron map indicate that sediments were transported from north to south through fairways to the east and west of the centrally located salt stocks. The eastern depocenter contains 1000 ms of sediment. The eastern depocenter lies downthrown from a prominent fault. A salt-cored high separates the two depocenters.

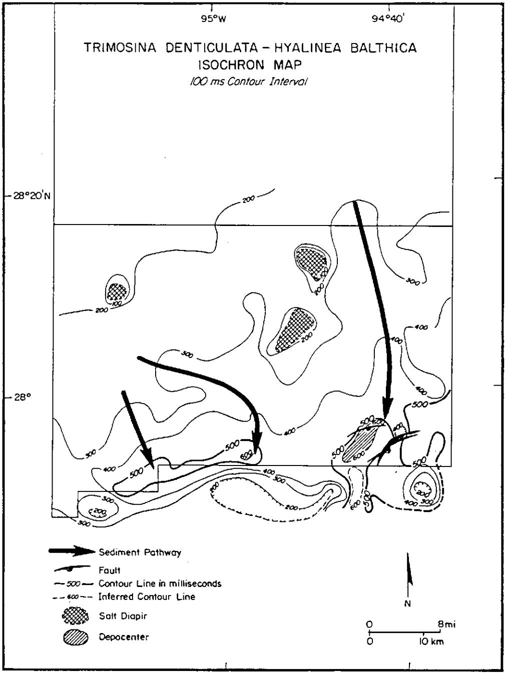


Figure 17. *Trim A-Hyal b* isochron map.

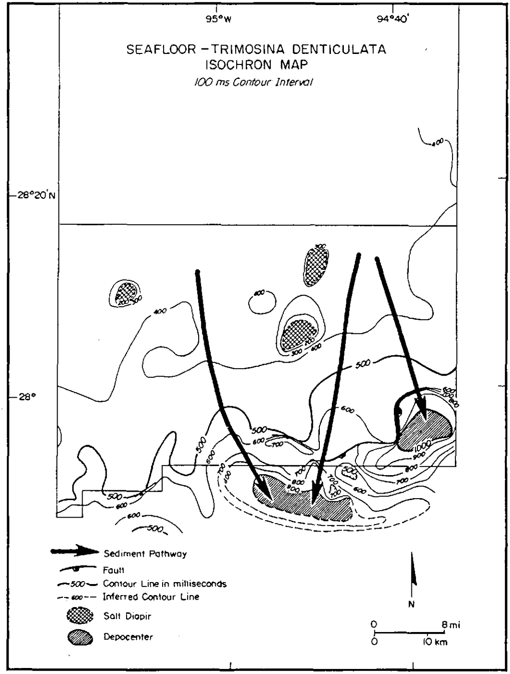


Figure 18. Seafloor-*Trim A* isochron map. Three sediment pathways appear. Two converge in the southern depocenter. The third feeds the eastern depocenter.

CHAPTER V

DISCUSSION

Time Structure Maps

All structure maps have more widely spaced contours in the north than in the south. The shelf edge for a given horizon is located where contours steepen and faults connect across the area. Closely spaced contours indicate thickening of sediment. Shelf-edge-sediment loading initiates faulting.

The extensive down-to-the-basin growth fault systems seen in the *Glob alt* horizon divide the strata into local fault controlled features (Figure 11). By *Trim A* time evenly spaced contours indicate a more uniform pattern of deposition (Figure 14). Salt is another controlling element. Particularly in the East Breaks Area, salt and salt withdrawal basins alternate. As the sediments accumulated at the shelf edge, underlying salt began to move and salt withdrawal basins formed as the salt flowed into salt stocks and massifs. A pattern of troughs adjacent to salt massifs appears on the structure maps. These troughs were probably the avenues along which sediment traveled to the basin. All structure maps show the East Breaks salt withdrawal basin, a major depocenter for the area.

Isochron Maps

The thickest portion of each isochron map points to the the shelf edge. At the Galveston South-East Breaks boundary, which coincides with the present shelf edge, thin contour intervals alternate with thick ones. The thins result from salt uplift while the thicks result from shelf edge sedimentation into the depression created by salt withdrawal and faulting. Pathways to the depocenter form from lows adjacent to large salt bodies. These lows appear on the time structure maps (Figures 11-14). The sediment pathway arrows, based on seismic evidence, and structure and isochron maps, suggest probable transport directions.

Sediment pathways exist in the western part of the area. These features are similar in architecture to those leading to depocenters in the eastern part of the area. A salt cored high lies in southwestern part of the area. A slope salt withdrawal depocenter, close to the 606 m (2000 ft) marker of water depth, probably occurs just beyond the southern limit of data. Thin sediments occur on top of salt cored highs because less sediment was deposited on the structural high than in the neighboring lower areas.

The *Ang B-Glob alt* deposits occurred over a span of 1.5 Ma (between 1.3 Ma and 2.8 Ma). The interval comprises two complete systems tracts (Figure 2). The depositional rate was 700 ms/Ma. The *Hyal b-Ang B* interval is the thinnest of the four isochrons. Deposition occurred over .2 Ma (from 1.1 Ma-1.3 Ma) at a rate of 2500 ms/Ma. The thinnest interval during *Hyal b-Ang B* lies directly above the mounded *Ang B-Glob alt* depocenter. During *Hyal b-Ang B* time less sediment was deposited on the *Ang B-Glob alt* mound, which was structurally higher than surrounding deposits. Consequently, the thinnest *Hyal b-Ang B* isochron overlies the thickest *Ang B-Glob alt* isochron. The depocenter for *Hyal b-Ang B* lies in the rollover of a fault which appears to terminate in the underlying salt (Figure 10). Sediment was deflected around the mounded paleo high and deposited into the depocenter.

The *Trim A* extinction datum (.65 Ma) coincides with a lowstand while the *Hyal b* datum (1.2 Ma) occurs during a highstand. The deposition period for the *Trim A-Hyal b* interval was relatively short: .45 Ma (from .65 Ma-1.1 Ma).

The depositional rate for *Trim A-Hyal b* was 1300 ms/Ma. It is possible that the eastern depocenter extends into the East Breaks Area or that there is a third 600 ms thick depocenter between the salt cored highs in East Breaks. The latter possibility is shown by a dashed line in Figure 17.

The Seafloor-*Trim A* deposits occurred over .65 Ma. The depositional rate was 1400 ms/Ma for the western depocenter and 1500 ms/Ma for the eastern depocenter. The western depocenter, located in East Breaks, may have originally been two smaller basins which merged as a result of salt withdrawal.

Salt-Depocenter and Fault Map

The superposition of depocenters on the salt map shows the relationship of depocenters to salt structures (Figure 7). The map verifies that all depocenters lie close to salt bodies. Although all depocenters are salt withdrawal basins, presence of salt is not enough to establish a depocenter. Sediment loading at the shelf edge plays an important role in creating a depocenter. Fault systems also exercise dominant control on the depocenters. With one exception, the depocenters lie within the major growth fault system close to the present shelf edge (Figures 11-18). The large salt bodies in the central and western regions are not associated with depocenters. They lack the growth faults and proximity to the shelf edge necessary for the formation of depocenters. Growth faults parallel paleo shelf edges. At the shelf edge the slope changes from less than 1° to more than 1°. This change in slope, coupled with sediment loading, creates a zone of weakness. Sediment deposited at the shelf edge initiates salt movement which induces faulting in this zone of weakness. These faults accommodate sediment on the downthrown side.

Paleo Shelf Edge and Facies Maps

I used seismic lines to find paleo shelf edges. Figure 19 shows the positions of shelf edges for the four mapped Pleistocene horizons. It is clear from the figure that shelf edges prograde basinward through time. I used reflection patterns and paleoenvironmental data to determine the seismic facies. Variable discontinuous facies predominate the three oldest intervals (*Trim A-Glob alt*), while variable continuous facies predominate the youngest (Seafloor-*Trim A*). Faulting accounts to a large extent for the discontinuous nature of the predominate facies type of the three lowest horizons (*Trim A-Glob alt*). The variable nature of the reflections indicates interbedded high and low energy deposits. Most of the variable continuous and discontinuous reflections are parallel which is characteristic of a shelf environment. Hummocky and progradational reflections suggest that the shelf edge is near. Chaotic facies are associated with salt movement and appear either on the shelf as rims around the salt body piercing an horizon or on the upper slope as a facies unit. Low amplitude facies, appearing only on the shelf, suggest a uniform energy depositional environment. These may be interpreted as either marine clastics deposited by low energy turbidity currents or fluvial and wave transport processes (Sangree and Widmier, 1977). Also appearing only on the shelf, high amplitude continuous reflections are typically interpreted as shallow marine clastics deposited primarily by wave transport processes (Sangree and Widmier, 1977).

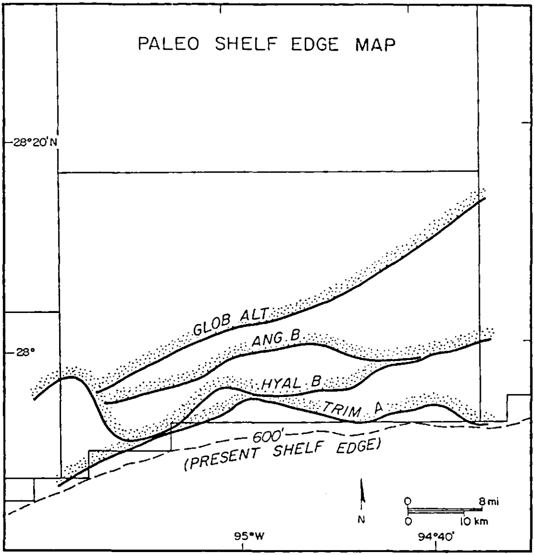


Figure 19. Paleo shelf edge map.

Variable discontinuous reflections predominate in the *Ang B-Glob alt* interval; however, a large hummocky zone, probably due to lowstand deposits, encompasses the central eastern portion of the area (Figure 20). *Glob alt* time corresponds to a third order sea level lowstand (Haq et al, 1987). The *Glob alt* sequence boundary is jagged due to erosion during a lowering of sea level. Thus sediments deposited on the erosional *Glob alt* boundary must be lowstand deposits. Paleoenvironmental data, position of the paleo shelf edges, and the hummocky to variable discontinuous reflections indicate that the *Ang B-Glob alt* depositional environment was outer shelf to upper slope (Figure 20). During *Ang B-Glob alt* time, two apparently discrete zones of progradation appear within the Galveston South Area. Progradational dips vary from 2°-6°. Dips approaching 10° indicate high energy deposition, probably oblique progradation, while dips less than 1° signify low energy deposition, probably sigmoid progradation (Sangree and Widmier, 1977). Faults in the area generally obscure progradational patterns making it difficult to distinguish between sigmoid and oblique progradation.

Variable discontinuous reflections predominate the *Hyal b-Ang B* interval indicative of an outer shelf environment (Figure 21). The progradational sequence forms an elongated pattern across the area with dips ranging from 0.1° to 4°. Progradation in this interval and in the *Ang B-Glob alt* interval is restricted to the Galveston South Area. In the next two intervals, *Trim A-Hyal b* and Seafloor-*Trim A* progradation occurs at the Galveston South-East Breaks boundary. At or near this boundary in the *Trim A-Hyal b* interval hummocky, chaotic, and progradational patterns emerge (Figure 22). The depositional environment was outer shelf according to paleoenvironmental data, position of paleo shelf, and seismic facies patterns. Dips of 3° and 5° appear in relatively fault free areas within the progradational facies. Farther inland on the shelf, variable discontinuous reflections characterize most of the area.

Variable continuous reflections, indicative of a middle shelf environment, predominate the Seafloor-*Trim A* interval (Figure 23). Many of the faults do not extend into this interval, thus the complex sigmoid-oblique pattern is visible at the Galveston South-East Breaks boundary (Figure 24). Also present at the boundary are progradational, hummocky, and variable discontinuous facies. Progradational dip varies from 0.4° shelfward to 4° basinward. Progradation in the oldest two intervals remains in the Galveston South Area. With time the progradational facies shifts basinward towards the East Breaks Area. The progradational pattern marks the paleo-shelf edge. The complex sigmoid-oblique pattern indicates alternating deposition and bypass within a high energy environment (Mitchum, 1976).

Within depocenters reflection patterns are typically hummocky, variable discontinuous, or progradational. Progradational facies are not recognized near the southeast corner of the area, where most of the depocenters are located, because there salt domes and growth faults create hummocky to variable discontinuous patterns. The exception to the typical facies pattern for depocenters is found in the eastern Seafloor-*Trim A* depocenter where variable continuous reflections appear. Reflection patterns and paleoenvironmental data indicate a middle shelf environment. The eastern Seafloor-*Trim A* depocenter lies downthrown from growth faults between two salt domes suggesting that this is a local depocenter controlled by faults and salt. A more significant depocenter containing shelf edge clinoforms occurs downdip outside data coverage (Armentrout, 1987).

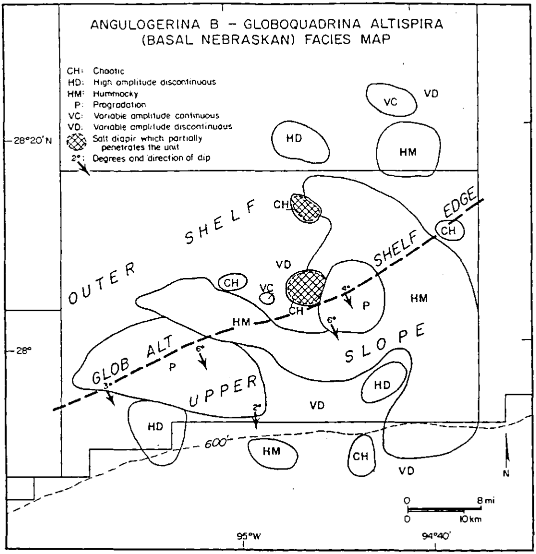


Figure 20. *Ang B-Glob alt* facies map. The predominant facies type is variable amplitude discontinuous. Progradation is NW-SE.

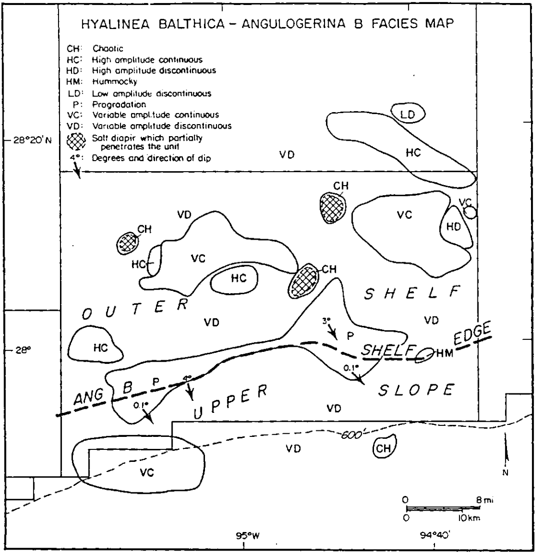


Figure 21. *Hyal b-Ang B* facies map. The predominant facies type is variable amplitude discontinuous. Progradation is NW-SE.

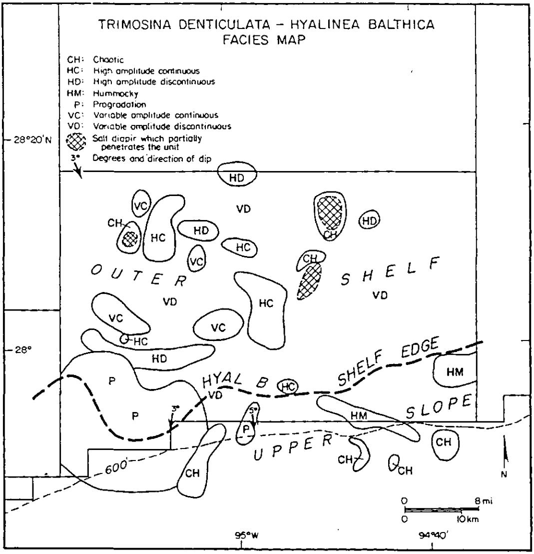


Figure 22. *Trim A-Hyal b* facies map. The predominant facies type is variable amplitude discontinuous. Progradation is N-S.

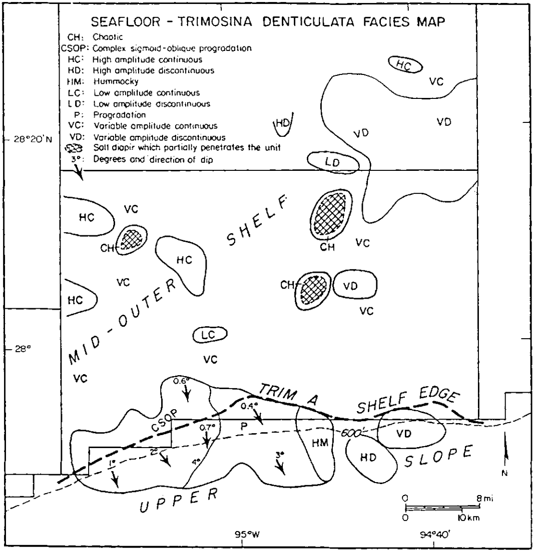


Figure 23. Seafloor-*Trim A* facies map. The predominant facies type is variable amplitude continuous. Progradation varies from NW-SE to N-S.

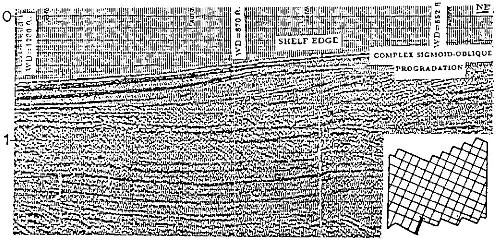


Figure 24. Seismic line showing progradation. In the shallowest interval, a complex sigmoid-oblique progradation pattern can be seen at the shelf edge.

CHAPTER VI

CONCLUSIONS

Structure maps show complex faulting and salt intrusions during *Glob alt* time. By *Trim A* time the contours indicate general northwest-southeast trends and indicate fault trends which do not always interrupt the horizon. Salt pierces all the horizons in the central part of the area while salt appears only as structural highs in the southern part of the area. The traditional view of salt is that it moves downslope. However, the salt distribution map and seismic lines show that salt fed in the immediate vicinity of the domes also moves updip or vertically. Faults merge to form fault systems which dominate the southern part of the area. In the southeast, the fault systems cut the present shelf edge at approximately 30° because here the shelf has prograded significantly since *Glob alt* time. Evidence for paleo shelf edges appears on the seismic lines. In addition, the fault system and the steepening of contours on the structure maps indicate the position of the paleo shelf edges. On the facies maps the shelf edges coincide with progradation. Shelf edges have prograded basinward through time. Isochron maps indicate that the sediment was transported from north to south via lows which formed in response to salt movement. A comparison of isochron maps to the shelf edge map shows that depocenters lie at their age equivalent shelf edges or upper slopes. The depocenters may be part of delta complexes. The eastern Seafloor-*Trim A* depocenter coincides with Suter and Berryhill's lowstand shelf edge delta (Suter and Berryhill, 1985). The large western Seafloor-*Trim A* depocenter is part of the East Breaks salt withdrawal basin. Movement of the large shelf edge salt massif and associated faulting provide accommodation space for the western Seafloor-*Trim A* depocenter and the *Hyal b-Ang B* depocenter. Sediments were deposited in these overlapping depocenters by turbidity currents (Bluestone, personal communication). Faults, salt, and proximity to the shelf edge determine whether a depocenter will form.

Future oil and gas prospects might lie in the progradation area just south of the limit of data near the 2000 feet (610 m) water depth marker in a salt withdrawal basin or on the flanks of salt domes. Also worthy of further exploration are the stacked depocenters in northern East Breaks and the deltaic Seafloor to *Trim A* depocenter.

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VITA

Sandra E. Brooks was born in Dallas, Texas. She graduated with honors from The Hockaday School and received a B.A. in Psychology from Vanderbilt University in 1973. She received a B.S. in Geophysics from Texas A&M University in 1984. Since that time she has pursued the Master of Science degree in Geophysics. She is presently associated with K.W. Brown and Associates, College Station, Texas.

Her permanent address is 5471 Timberline Dr., College Station, Texas 77845.

The typist for this thesis is Sandra E. Brooks.